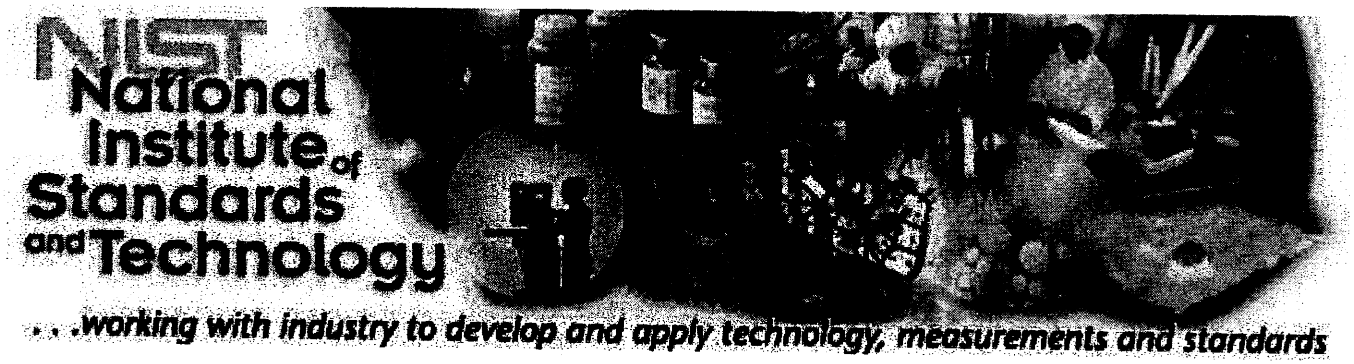

Verification and Validation of CFAST

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Analysis and Prediction Group
Building and Fire Research Laboratory

5th Meeting of the International Collaborative Fire Model Project

May 2-3, 2002

The Three Legs of Modeling for Public Safety

- Zone Modeling
  - **CFAST (and the GUIs)**

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- Validation and Verification
  - **Through statistical analysis**

- Data for comparisons
  - **FASTData database development**

Modeling

- CFAST - zone model
  - Large (complex) building simulation
  - Input/model/output
- FAST/FASTLite/FireWalk/FireCAD
  - GUI interfaces for fire models
  - Includes simple back of the CRT calculation

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Concept of a Zone Model

Each compartment is subdivided into "control volumes," or zones. Conservation of mass and energy is applied to each zone.

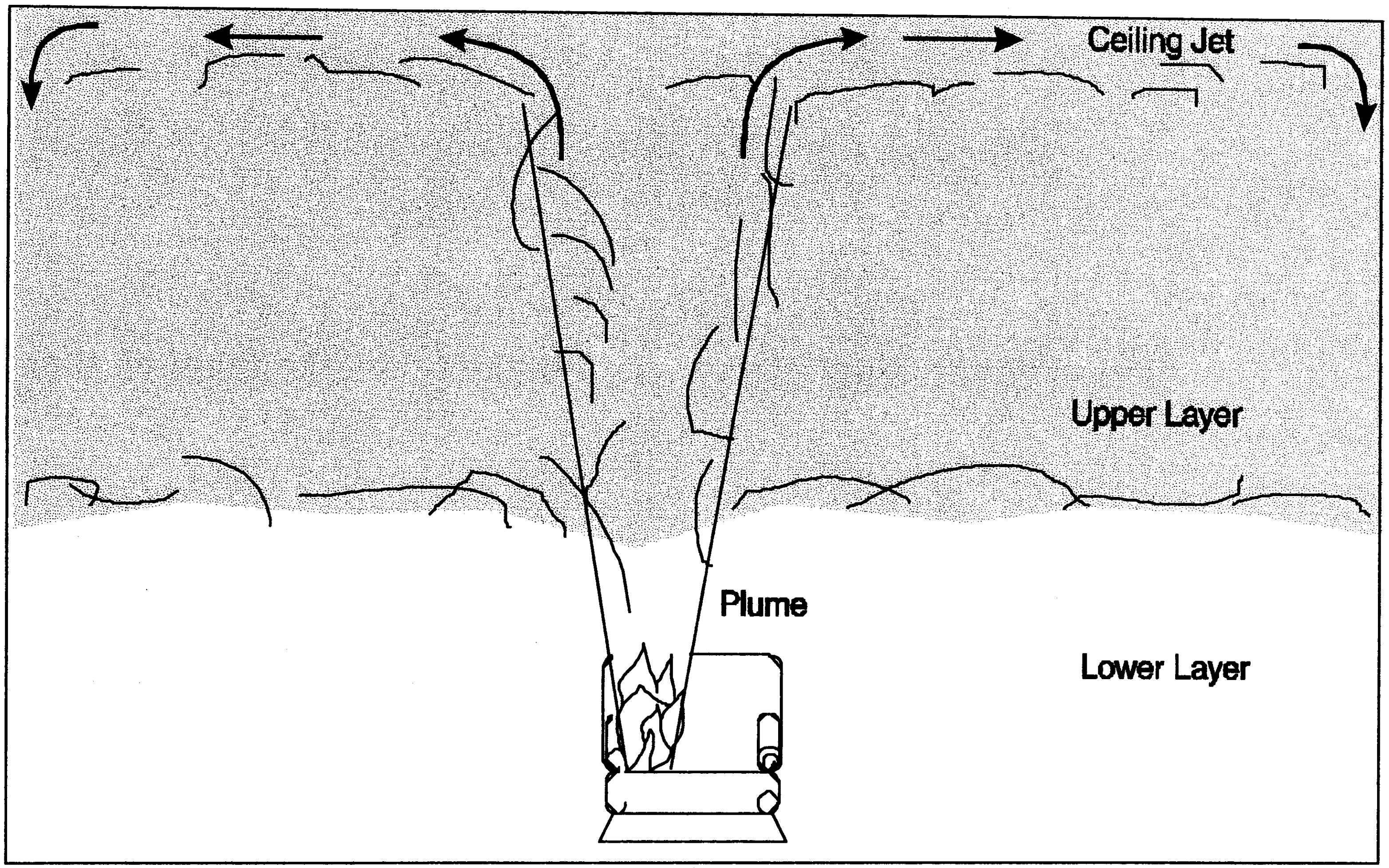
A few zones (2 to 10)

Predictive equations are derived from conservation of energy and mass (momentum at boundaries)

Use ordinary differential equations rather than partial differential equations

Adding phenomena is *relatively* easy

Concept of a Zone Model



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Why Is this Modeling Important?

- Speed – algorithm implementation is very important
- Do parameter studies of complex buildings
  - Complex and numerous connections
- Predict (small variations do not matter)
  - Environment (CO, …)
  - Insult to the structure

Zone Models in the U.S.

CFAST - 2.0.1 - HAZARD I version 1.2

CFAST - 3.1.5 being used in fire reconstruction

Compbrn III - UCLA - consulting with EPRI

BRI2 (Japan) - Factory Mutual Risk Analysis

Many specialize tools such as FPETool (ASET, ASCOS, ...)

Phenomena

Multiple compartments (60->~100)

- Variable geometry

Multiple fires

- Ignition: time, flux or object temperature

Fire plume and entrainment in vent flow

Vitiated or free burn chemistry

Four wall and two layer radiation

Four wall conductive heat transfer through multilayered walls, ceilings and floors

Wind effects

3D specification of the location of the fire and non-uniform heat loss thru boundaries

Phenomena

Generalized vent flow
- Horizontal flow (doors, windows , ...)
- Vertical flow (holes in ceilings/floors)
- Forced flow (mechanical ventilation)

Intercompartment heat transfer

Ceiling/floor

Horizontal - compartment to compartment

Horizontal smoke flow

Detection - smoke, heat

Suppression - heat release knockdown

Separate internal and external ambient(s)

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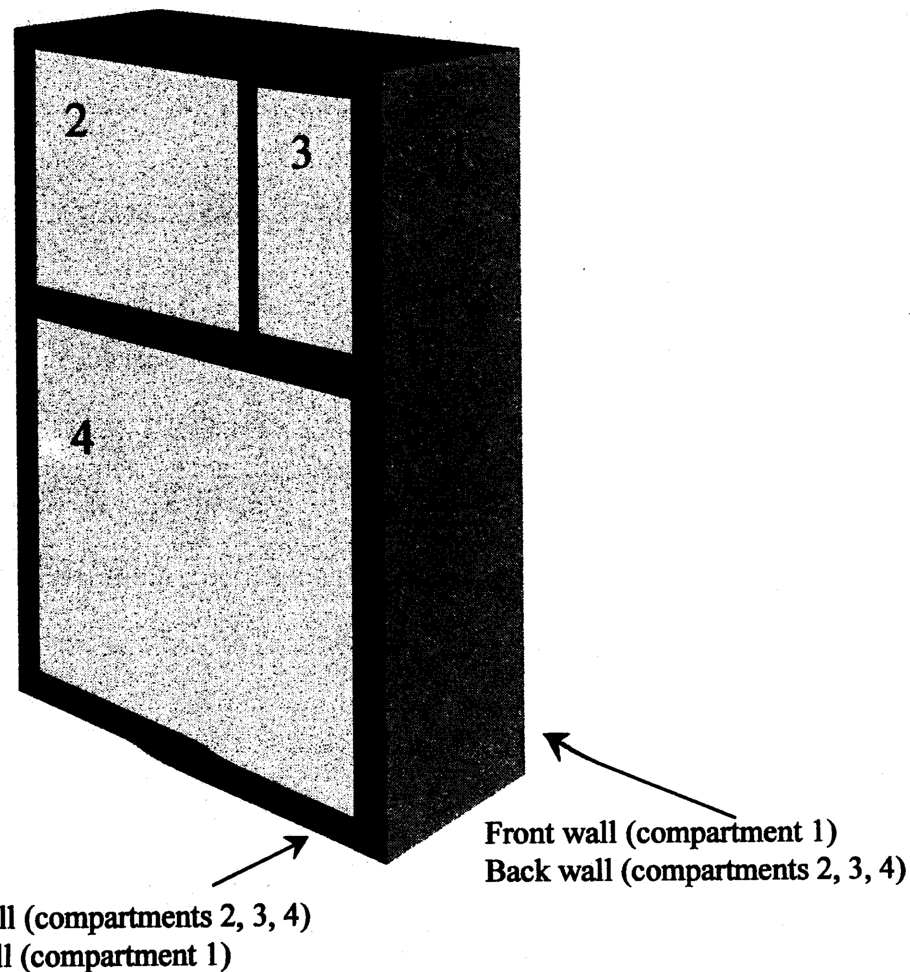
Intercompartment Heat Transfer (Horizontal Conduction)

Flux at rear of room 1 = weighted average of fluxes from front of rooms 2, 3 and 4 or ...

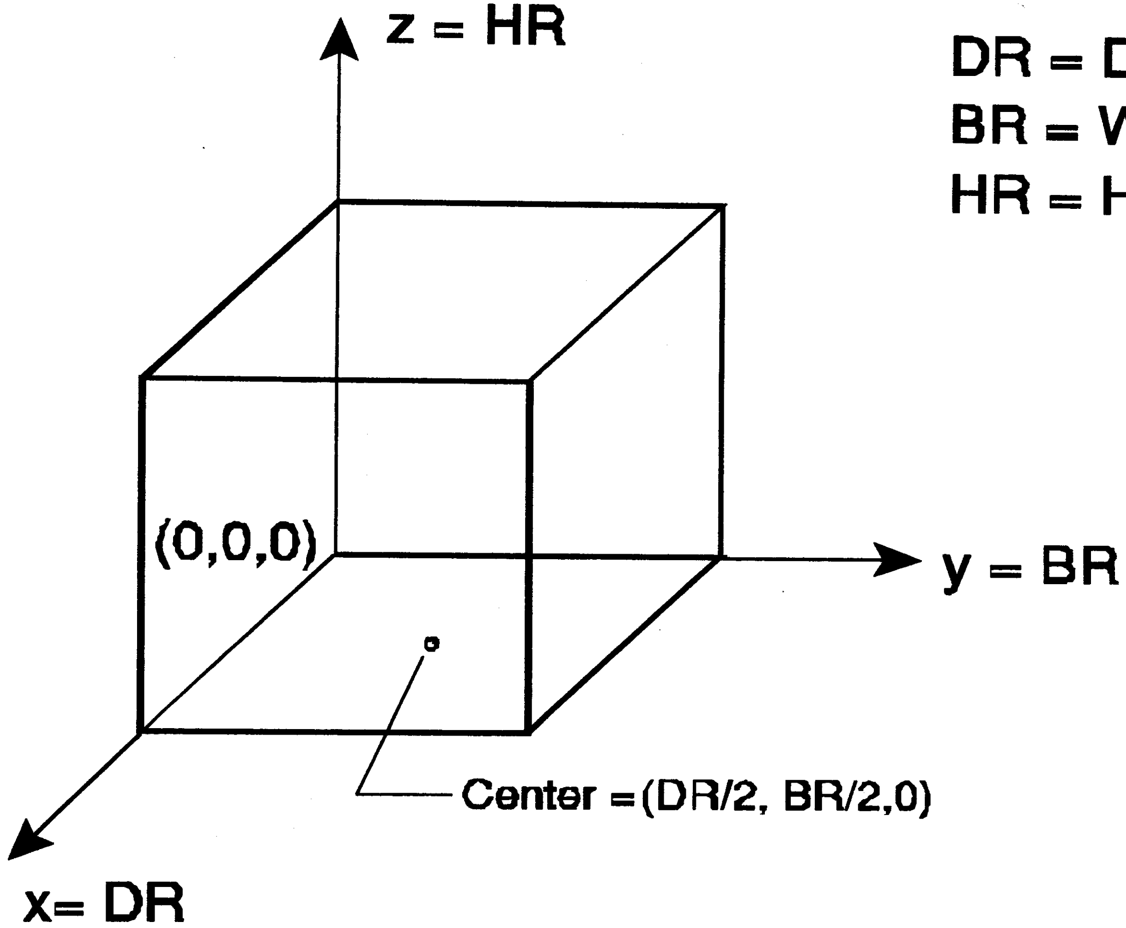
$$q''^{r}_{i,avg} = \sum_j F_{ij} q''^{f}_j$$

$q''^{r}_{i,avg}$	Average flux at rear of wall i
F_{ij}	Fraction of flux from the front of wall j contributing to the back of wall i
q''^{f}_j	Flux striking front of wall j

Wall joining compartments 1, 2, 3, 4

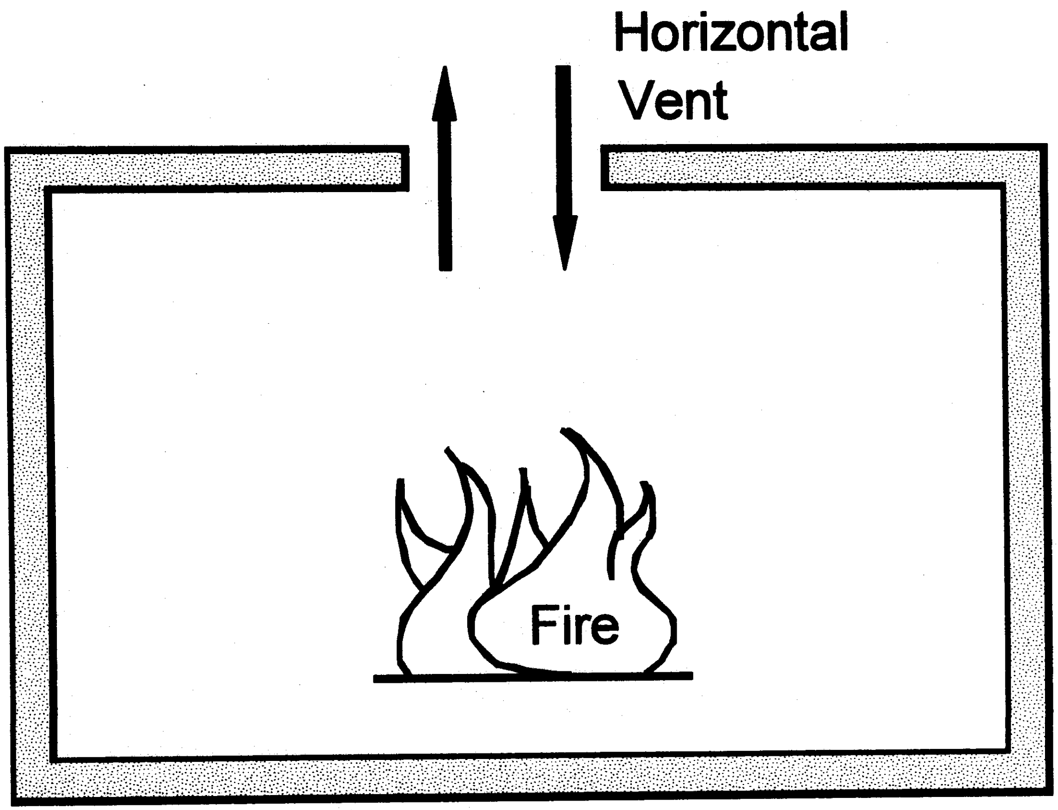


XYZ Positioning of Objects, Fires and Surfaces

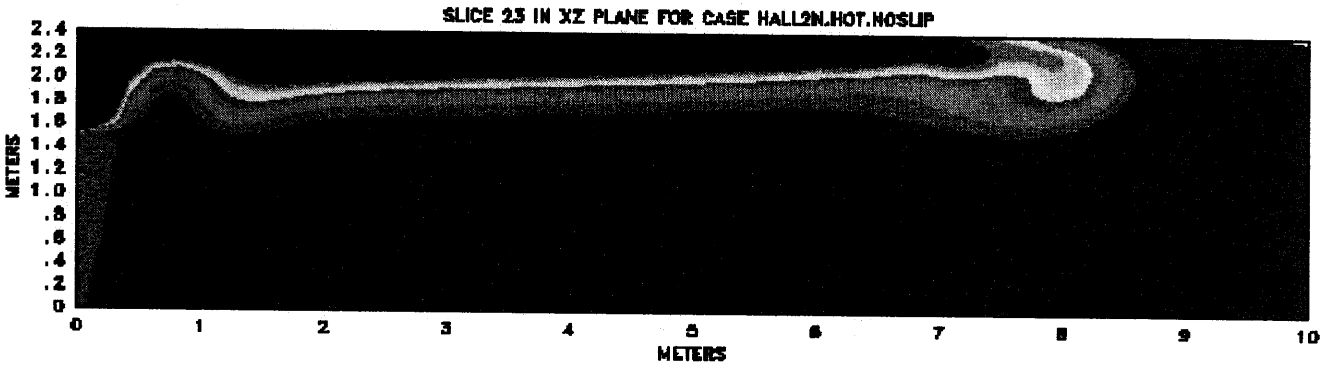


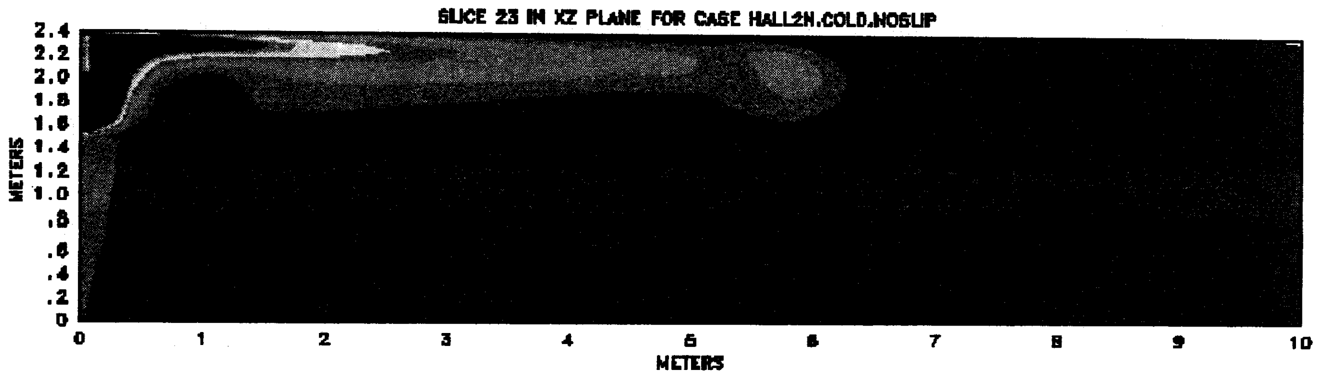
DR = Depth
BR = Width
HR = Height

Vertical Flow
(Horizontal Vents)

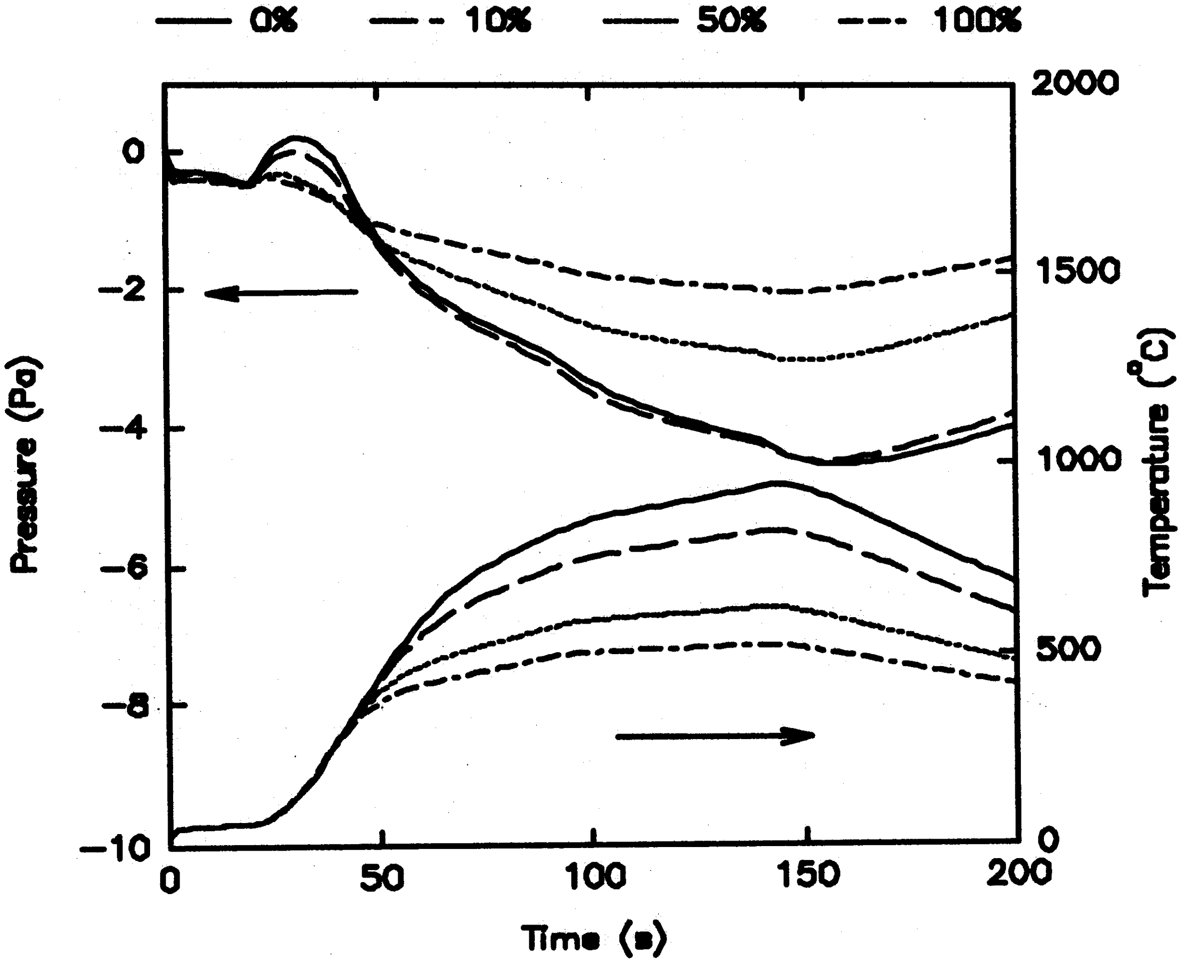


Corridor Flow





Leakage – Specification Errors



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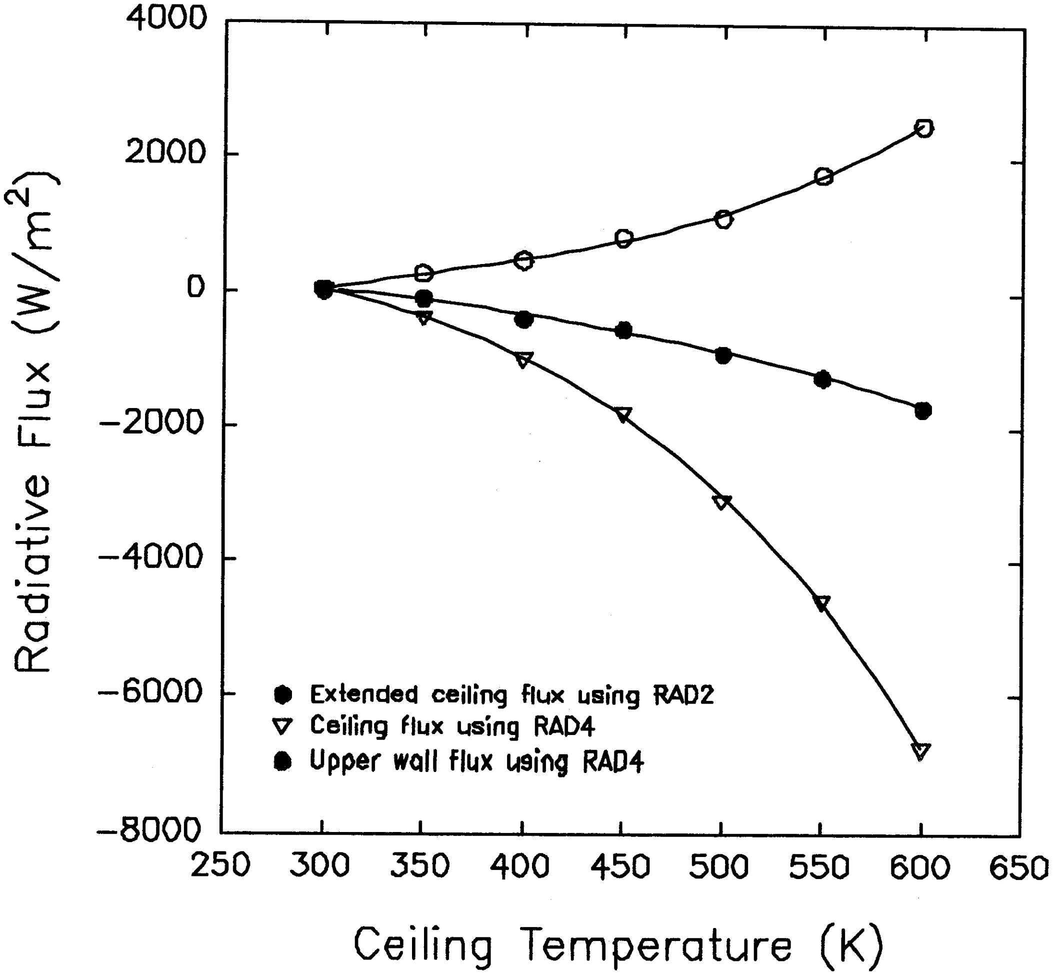
Effects we can examine closely



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Verification *vs* Validation

- Verification: insuring that the phenomenology is implemented correctly in the model
- Validation: insuring that a model makes the correct (expected) prediction for a given set of input data
- For public safety and finding economies of scale, both are important

Issues Related to Verification

- Comparison with experimental data, including error analysis
- Open system - published code (verification, not validation)
- Documentation - crucial
- Sensitivity analysis (suite)

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Quotes on Verification

- "The simulations generally compare favorably with the experiments"
- "Upper layer temperatures were not predicted well by either model"
- "Layer heights are well predicted by both models only in the bum room"
- "All of the models simulated the experimental conditions quite satisfactorily"
- "For the 4 MW fire size, all of the model do reasonably well"

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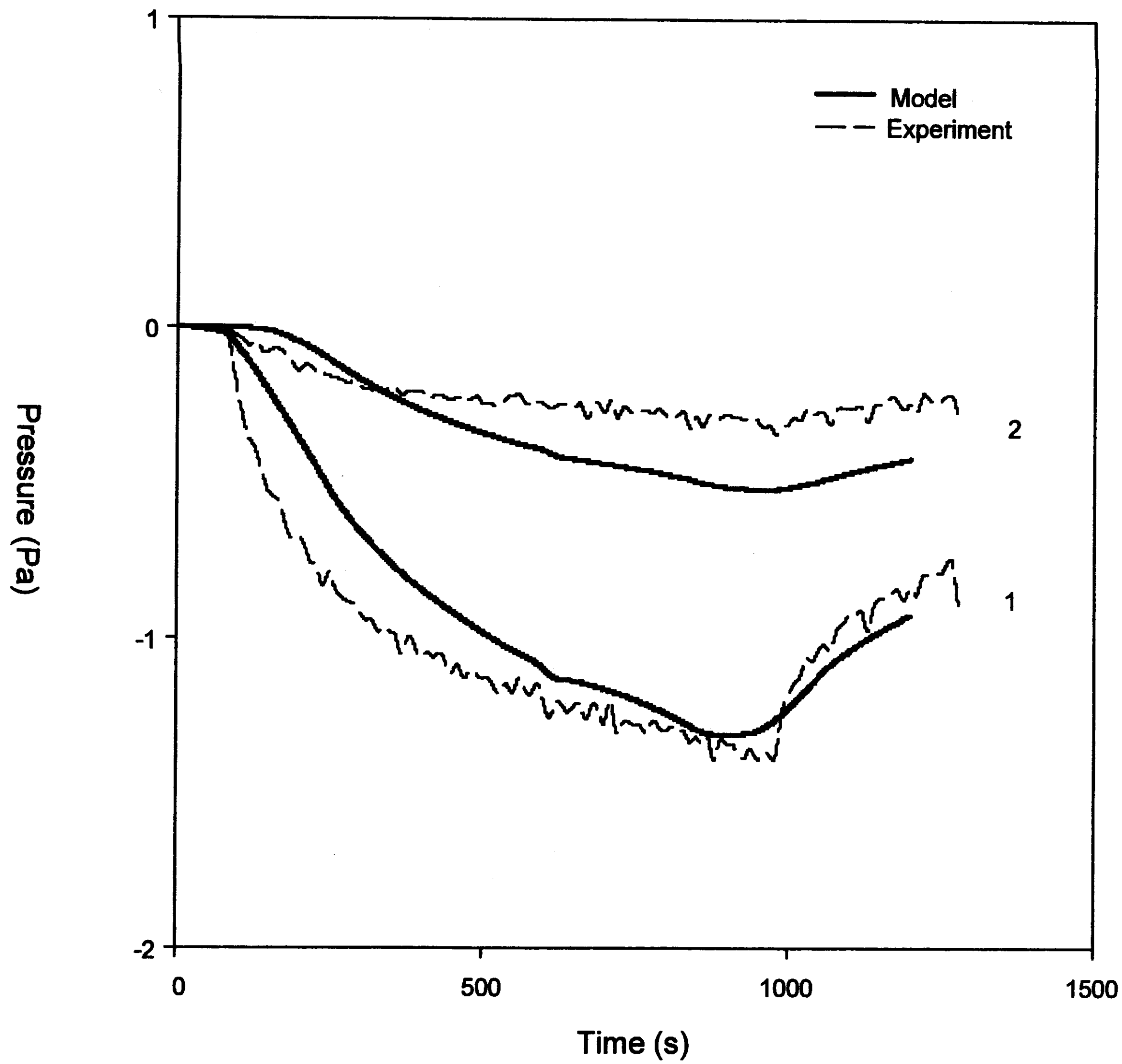
Statistical Verification



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May 2, 2002

BFRL

Possible "Norms"

$$\left\| \vec{x} \right\| = \sqrt{\sum_{i=1}^{n} x_i^2}$$

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$$\langle \vec{x}, \vec{y} \rangle = \frac{\sum_{i=1}^{n} (x_i - x_{i-1})(y_i - y_{i-1})}{t_i - t_{i-1}}$$

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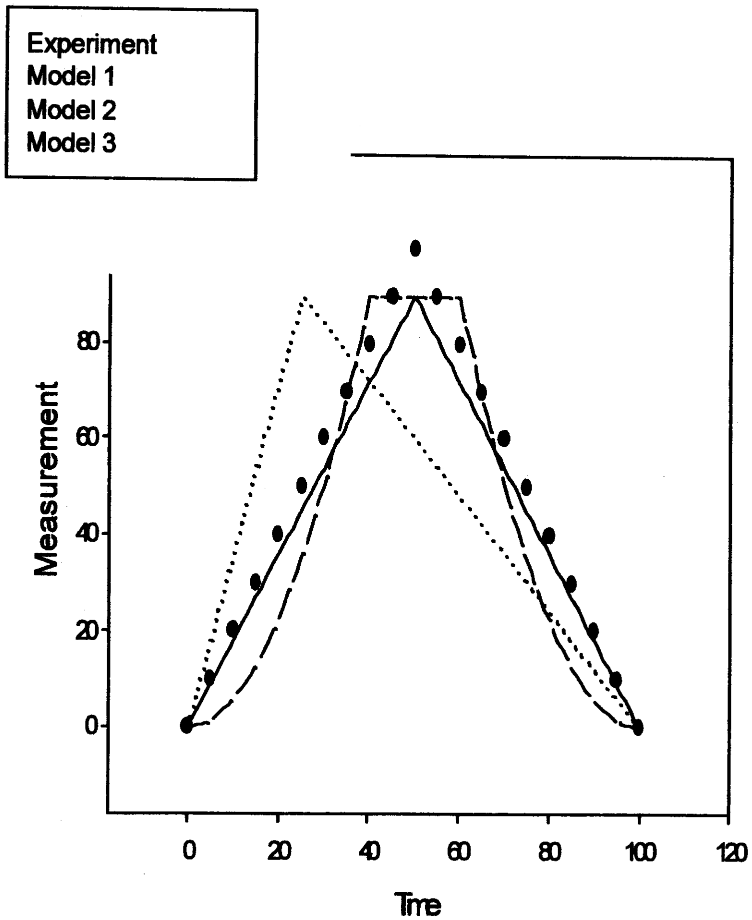
Example of Metrics



product definitions

Geometry	Model	Relative Difference	Cosine
Euclidean	1	0.10	1.00
	2	0.40	0.92
	3	0.20	0.98
Hellinger	1	0.10	1.00
	2	0.94	0.58
	3	0.74	0.77
Secant	1	0.10	1.00
	2	0.92	0.58
	3	0.66	0.83
Hybrid	1	0.10	1.00
	2	0.64	0.78
	3	0.43	0.91

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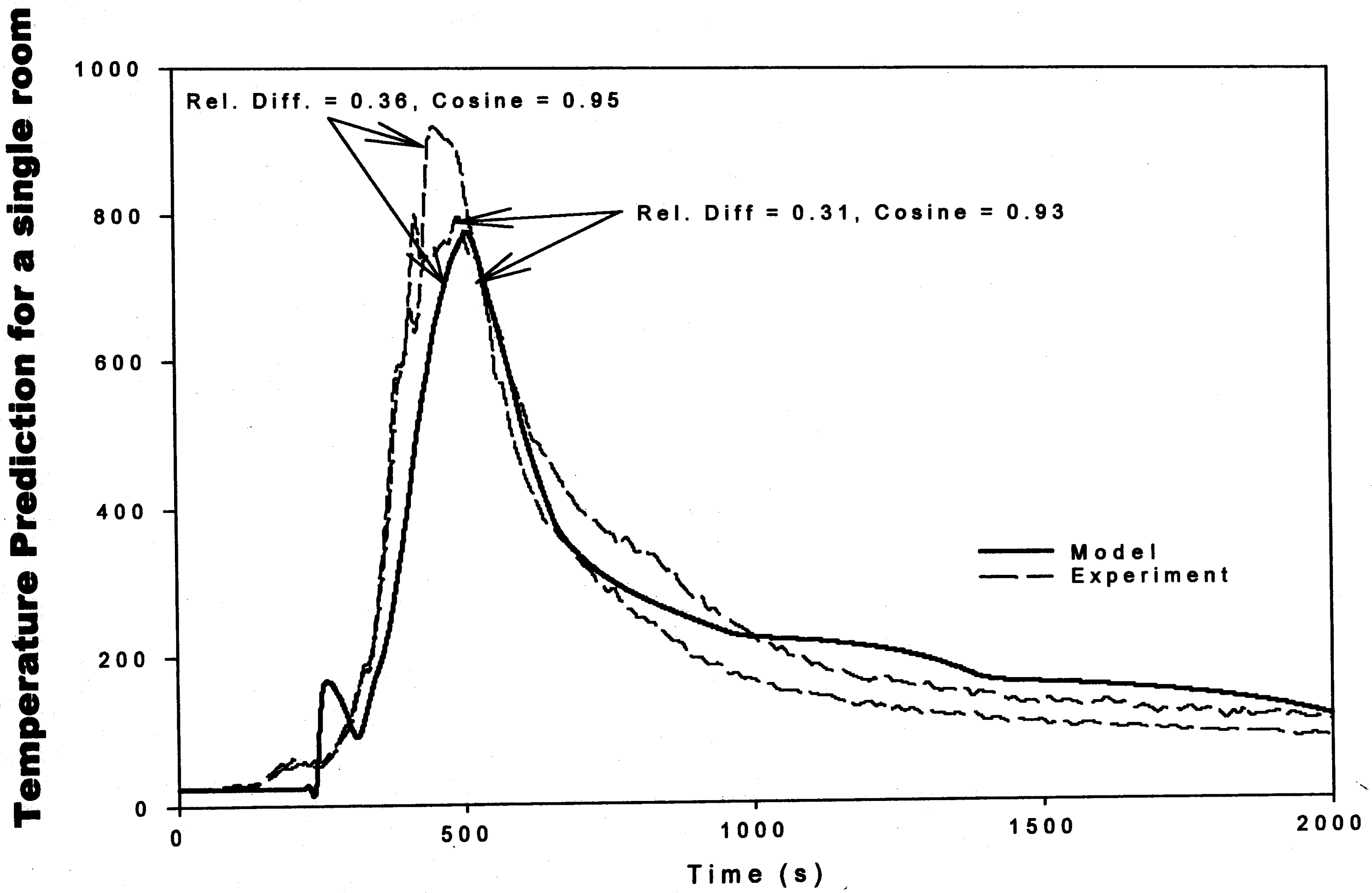
One of our real room comparisons



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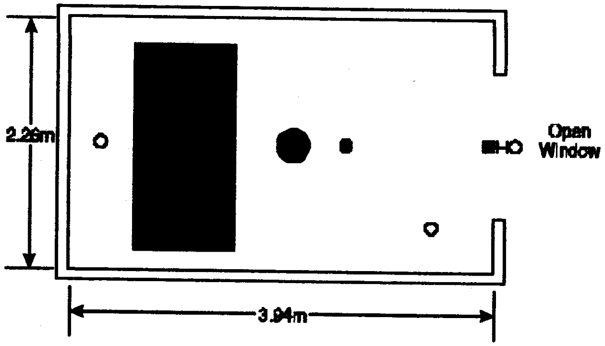
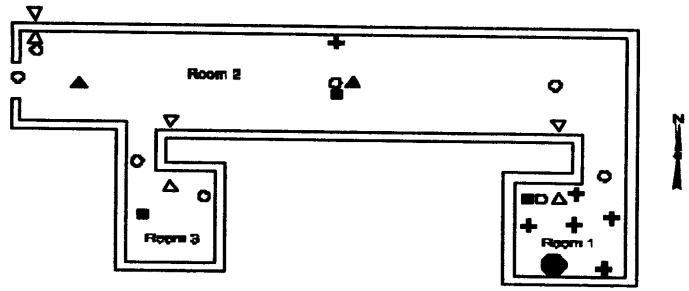
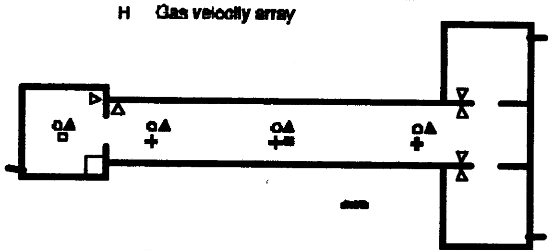
1, 3, 4 and Multistory Configurations



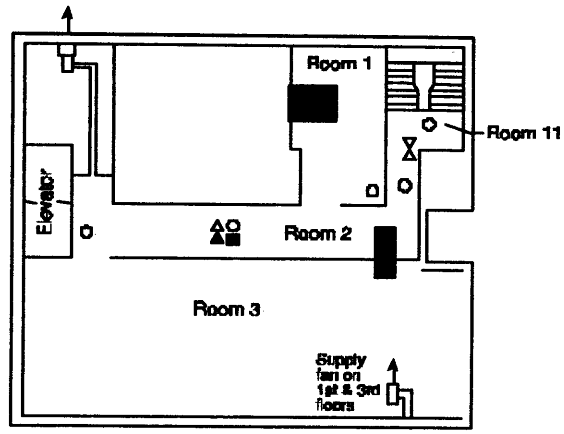
- Fire source, specimen mass loss
- Fire source, gas burner
- Gas temperature array
- Heat flux, floor level
- Gas concentration (CO, CO$_2$, O$_2$)
- H Gas velocity array



- Fire source, gas burner
- Gas temperature array
- Surface temperature
- Gas concentration (CO, CO$_2$, O$_2$)
- Differential pressure array
- Smoke obscuration, horizontal & vertical



- Fire source, gas burner
- Gas temperature array
- Surface temperature (ceiling)
- Gas concentration (CO, CO$_2$, O$_2$)
- Gas concentration (CO, CO)
- Differential pressure array
- Smoke obscuration



Second Floor

Fire source, specimen mass loss
Gas temperature array
Gas concentration
Differential pressure (room 2 to room 4
do

An example with four real scale experiments

	Position / Compartment	Relative Difference	Cosine	Relative Difference	Cosine	Relative Difference	Cosine
Upper Layer Temperature and Interface Position							
		Upper Layer Temperature		**Lower Layer Temperature**		**Interface Position**	
Single-room furniture tests	1	0.31	0.95	0.47	0.92	1.38	-0.60
	2	0.36	0.93	0.63	0.78	0.63	0.78
Three-room tests with corridor	1	0.25	0.97	–	–	–	–
	2	0.26	0.99	–	–	–	–
	3	0.26	0.98	–	–	–	–
Four-room tests with corridor	1	0.51	0.93	0.33	0.95	2.26	0.06
	2	0.54	0.91	0.52	0.87	–	–
	3	0.36	0.97	0.78	0.86	–	–
	4	0.20	0.98	–	–	–	–
Multiple-story building	1	0.28	0.97	–	–	–	–
	2	0.27	0.96	–	–	–	–
	7	2.99	0.20	–	–	–	–
Gas Concentration							
		Oxygen		**Carbon Monoxide**		**Carbon Dioxide**	
Single-room furniture tests	1	0.48	0.90	0.93	0.66	0.69	0.93
Four-room tests with corridor	1	0.85	0.53	1.05	0.61	1.16	0.63
	2	0.93	0.39	1.02	0.57	0.90	0.63
Multiple-story building	2	0.74	0.68	0.72	0.90	0.87	0.93
Heat Release, Pressure, and Vent Flow							
		HRR		**Pressure**		**Vent Flow**	
Single-room furniture tests		0.19	0.98	–	–	0.61	0.79
Single-room tests with wall burning		0.21	0.98	1.31	0.80	–	–
Three-room tests with corridor	1	0.43	0.96	0.15	0.99	0.14	0.99
	2	–	–	0.68	0.98	0.20	0.98
Four-room tests with corridor		–	–	6.57	0.74	–	–
Multiple-story building	1	–	–	1.12	-0.41	–	–

Steps for Verification

- **1) Maintain a set of test data: small scale to real scale**
  FASTData (US), several others; not as useful as it should be

- **2) Maintain a set of data files which have given us problems in the past**
  Many of these are usability issues, but that affects predictions as well

- **3) Do are formal comparison of a "released" model with the results of past calculations**
  bintoasc, compare, compinfo - variable.dat includes allowable variance
  Appendix in technical guide
  Did through 3.1.6

- **4) Maintain a history of CFAST - earliest is March, 1989**
  In principle, one can reconstruct the executable for each release including intermediate versions. In reality this is not a practical exercise.

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Conclusion

Validation and Verification are important

Statistical comparison (with metric) is possible

Needs more work